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ORIGINAL ARTICLE

Simulation of the spatial distribution of thinning area under different silvicultural subsidy systems in Japanese plantation forests

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Abstract

The aim of this study was to simulate the effect of spatial thinning on the distribution of non-industrial private forests (NIPFs) and predict the thinning area under different subsidy systems in Hokkaido prefecture, Japan. The simulated thinning area is based on a Geographic Information System (GIS) and an algorithm that considers the stand condition and applicability of different subsidies for conducting thinning. The accuracy of the simulations was checked by comparing observed and predicted thinning area data. In Shimokawa municipality the thinning area was significantly smaller than in Furano municipality, where the rules governing subsidy allocations are more relaxed. The coefficients of determination (R^2), which were calculated by comparing the estimated and observed jointly implemented thinning areas, defined as areas in which thinning occurred in several adjacent sub-compartments, were 0.88 and 0.89 in Furano and Shimokawa, respectively. Although our algorithm slightly overestimated the jointly implemented thinning area, the estimated average thinning area was within the two-sided 95% confidence interval for the observed area. By applying the model and linking our simulation results to the GIS, the total potential distribution of jointly implemented thinning area was visualized in two geographic areas that have different subsidy systems.

Key words

GIS, private forest, thinning practice area, subsidy

Introduction

The owners of non-industrial private forests (NIPFs) hold large areas of commercial forest across the world, including the USA (Dennis 1990; Pattanayak et al. 2002; Kline et al. 2002; Liao and Zhang 2008), Europe (Kurttila et al. 2006; Bolkesjø et al. 2007; Rodríguez-Vicente and Marey-Perez 2009) and Canada (Zhang and Pearse 1997). Previous studies have considered the behavior of NIPF owners and their personal aims and ob-

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jectives, the financial resources they have available, and possible constraints to the successful management of their forests (Jansen and Di Gregorio 2003; Rodríguez-Vicente and Marey-Perez 2009). Indeed, no analysis of land-use dynamics in rural areas or effects of forestland tenure regimes would be complete without considering NIPF ownership. However, it is difficult to define the meaning of the term NIPF precisely, since the nature of NIPF ownership differs considerably between countries (Herbohn 2001). Furthermore, even within countries NIPF owners manage their land for a wide variety of purposes, so the management practices and value of these forests are very diverse; some NIPF owners carry out intensive management (like industrial owners), while others have no forest management strategy (Siry et al. 2005). Therefore, it is important to consider the features of NIPFs to optimize multi-purpose forestry policies and plan sustainable forest management regimes, develop regional-level forest economic strategies and maintain biodiversity levels (Kurttila 2001; Van Deusen 2001; Bolkesjo and Baardsen 2002; Pattanayak et al. 2002; Favada et al. 2007; Hyytiainen and Penttinen 2008).

Analyzing and modeling landowner behavior in terms of silvicultural practices is important for optimizing multi-purpose forestry policies and for regional-level sustainable forest management. Aspects of silvicultural activities that may differ between NIPF and other owners (and thus should be considered) include timber harvesting methods (Dennis 1990; Bolkesjo and Baardsen 2002; Kline et al. 2002; Vokoun et al. 2006), afforestation and reforestation programs (Zhang and Pearse 1997; Pattanayak et al. 2002; Lewis and Plantinga 2007) and timber stand improvement (TSI) techniques (Zhang and Pearse 1996; Zhang and Flick 2001). Previously, modeling has enabled us to estimate and predict timber harvesting, reforestation and timber stand improvement (TSI) parameters in NIPFs. However, it is difficult to estimate and predict these parameters exactly for NIPFs because of the diversity of the landowners' objectives and management strategies.

Previous studies have used two approaches for analyzing NIPF forest owner behavior. The first is a scenario-based approach (Gottschalk et al. 2005; Mattison and Norris 2005), in which a microeconomic model is used to determine how different forest policies and subsidy systems may affect their forest management behavior and provide statistically-significant predictions for simulating the effects of forest policy and subsidy systems on the status of their forests. Using this approach, Beach et al. (2005) showed that the most important factor for predicting NIPF forest owner behavior was the current government policy, particularly the subsidy system (Koskela et al. 2007). The second approach is based on a GIS (Gustafson and Crow 1994; Proe et al. 1997; Tang et al. 1997; Gottschalk et al. 2005). This has obvious merits since it is important to consider spatial information at the landscape level for analyses of spatial biodiversity, risk assessments, restricting simultaneous harvesting, and developing multi-purpose forestry-level policies. This has obvious merits since it is important to consider spatial information at the landscape level for analyses of spatial biodiversity, risk assessments, restricting simultaneous harvesting and developing multi-purpose forestry-level policies. In addition, in econometric modeling of NIPFs, spatial information (in terms of plot/resource condition) is highly significant, ranking second after government policy according to Beach et al. (2005). Therefore, in this approach simulations of landowner behavior (based on different silvicultural regimes) are linked to information acquired using a Geographic Information System (GIS) (Chertov et al. 2002). Furthermore, a GIS-based approach is not only effective for modeling NIPF landowner activity, but also for visualizing the effects of different policy scenarios on NIPFs.

Approximately 58% of planted forests in Japan are privately owned. These NIPFs generally consist of numerous small (less than 5 ha) forests owned by different people (Forestry Agency 2007), and the forest policy subsidy system is known to strongly affect their management practices (Hiroshima and Nakajima 2006). Thus, it would be highly valuable for policy-makers to be able to model the effects of different forest policy scenarios on NIPF owner behavior, and to be able to visualize the effects using a GIS. Furthermore, due to the socio-economic situation in Japan, there has been little financial incentive to practice sound forest management and profits have been very low as a result of decreasing timber prices. This has resulted in increased areas of unmanaged and unthinned forests, many of which have been left untended for more than 10 years (Nakajima et al. 2007). Hence, there is an urgent need to improve the profitability of Japanese forestry, and to develop

greater understanding of the motivation and responses of NIPFs.

Due to the general lack of thinning, self-thinning has been increasing, accompanied by reductions in the carbon stock and adverse effects on forest ecosystem functioning. These developments are in direct conflict with a need to increase thinned areas of forest, relative to 1990 levels (Japanese Forestry Agency 2007), under Kyoto Protocol commitments (Houghton et al. 1997; UNFCC 1998; Robert et al. 2000; UNFCC 2002; IPCC 2003; Jansen and Di 2003). Thus, there are urgent needs to expand the areas that are rationally thinned, and to reduce the cost of the operations by increasing their scale through forest owner cooperation. Therefore, silvicultural practices are now supported by a subsidy system (Nakajima et al. 2007), under which forest owners are required to report the conditions of their stands and the silvicultural treatments they have applied. This information has been integrated by local governments in some regions with forest inventory and spatial (GIS) information.

Hokkaido is the largest prefecture in Japan and forest inventory data, GIS information and silvicultural practice records are collected here annually. The aim of this study was to develop a simulation model for the spatial joint implemented thinning distribution of NIPFs and predict the thinning area resulting from different subsidy systems. The simulated jointly implemented thinning area (thinning performed jointly by several owners, identified in the modeling described below as thinning performed in several adjacent GIS sub-compartments) was verified by comparing the data from the model with field data from two sites. In addition to presenting the model, in this paper the differences in the spatial thinning area distribution associated with different subsidy systems are analyzed and discussed.

Methods

Study sites

The forests that we studied were in the Furano and Shimokawa municipal regions (hereafter, simply Furano and Shimokawa, for convenience; Fig. 1), which are located in a subarctic zone, with an average annual temperature of approximately 5°C and rainfall of approximately 1000 mm. These forests cover a total area of 42,058 ha and 56,989 ha, respectively. The total privately-planted forest area in Furano is 6,167 ha, of which 1,609 ha (26%) is covered by Todomatsu (*Abies sachalinensis* F. Schmidt), 2,706 ha (44%) by Karamatsu (*Larix leptolepis* Siebold & Zucc), and 1,852 ha (30%) by other tree species, including Ezomatsu (*Picea jezoensis* Rehd.), Touhi (*Picea glehnii* Mast.) and Guimatsu (*Larix gmelinii* Kuzen.). The total privately-planted forest area in Shimokawa is 2,439 ha, of which 1,173 ha (48%) is covered by Todomatsu, 907 ha (37%) by Karamatsu, and 359 ha (15%) by other tree species. The proportion of stands owned by absentee forest owners in the Furano and Shimokawa regions is 48% and 26%, respectively. In Furano and Shimokawa, GIS information regarding private forests has been collected annually since 1974.

The central government and Hokkaido Prefectural government subsidize the thinning of planted forests for plantations of all tree species younger than 35 years, meeting approximately 70% of the thinning cost. In Furano, the 35-year age limit was removed in 2005 as part of a 'forest area recovery project' that was intended to expand the implementation of joint thinning of planted forests near the city. However, neither of the subsidy systems can be used in forests that have been subsidized in the preceding five years.

For the two study sites, forest inventory data on variables such as stand age, area, tree species, slope, address of the forest owner and site index, are available for the private forests. These inventory data have also been linked to sub-compartments included in a GIS. Historical records of silvicultural practices applied in each sub-compartment over the last 30 years have also been linked to the GIS, and a forest road map has been constructed for the study sites. The historical records include the number of years that thinning practices have been implemented, the sub-compartment numbers and their area.

Data analysis

Calculation of the jointly implemented thinning area

Using the above data we estimated the influence of different subsidy systems on the jointly implemented thinning area, as follows. The adjacent sub-compartments where thinning was implemented in each year from 2005 to 2007 were identified as joint implemented thinning areas. From responses to questionnaires sent

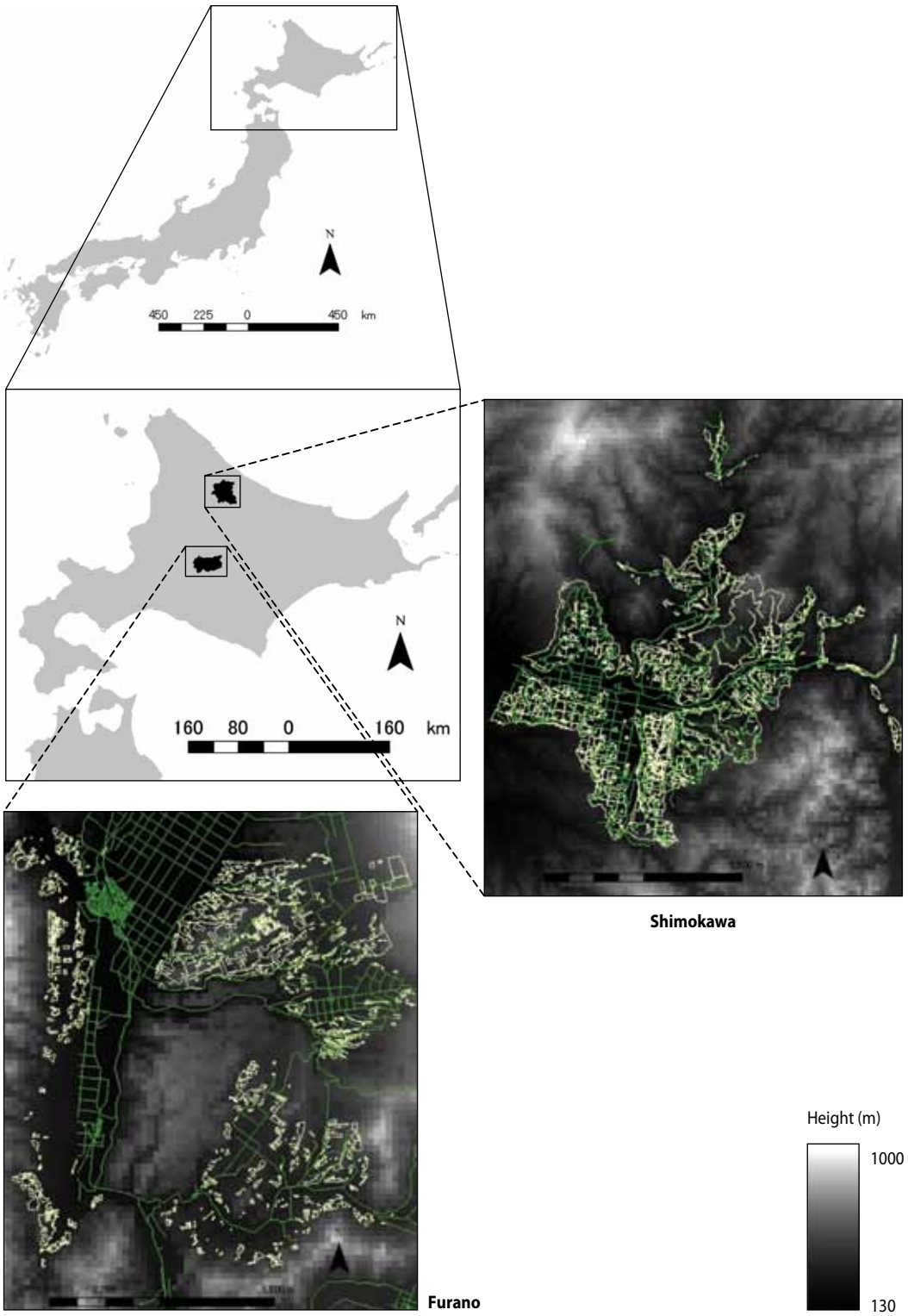

Fig. 1. Location of Furano and Shimokawa municipalities showing elevations and forest roads (green lines)

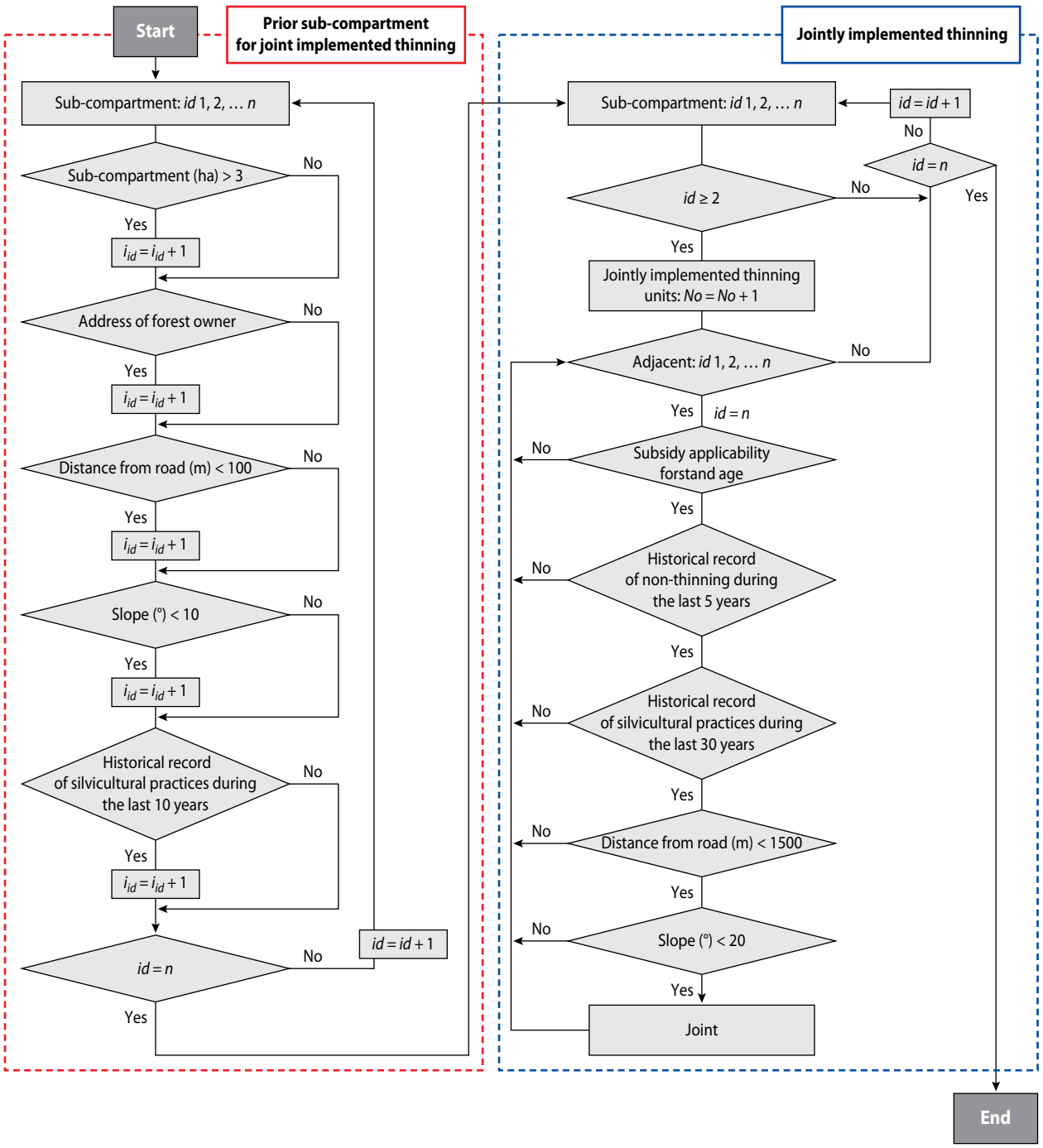
Start
Prior sub-compartment for joint implemented thinning
Jointly implemented thinning
Sub-compartment: id 1, 2, … n
Sub-compartment (ha) > 3
No
Yes
$i_{id} = i_{id} + 1$
Address of forest owner
Distance from road (m) < 100
Slope (°) < 10
Historical record of silvicultural practices during the last 10 years
id = n
id = id + 1
Sub-compartment: id 1, 2, … n
id = id + 1
id = n
id ≥ 2
Jointly implemented thinning units: No = No + 1
Adjacent: id 1, 2, … n
Subsidy applicability forstand age
Historical record of non-thinning during the last 5 years
Historical record of silvicultural practices during the last 30 years
Distance from road (m) < 1500
Slope (°) < 20
Joint
End

Fig. 2. Framework for the algorithm to simulate jointly implemented thinning from stand conditions and subsidy system

to members of forestry associations in Furano and Shimokawa, we found that almost 100% of the thinning area in the study sites had been subsidized. Therefore, using historical records regarding the silvicultural practices had been used, we calculated the jointly implemented thinning areas under the different silvicultural subsidy systems in Furano and Shimokawa. In addition, we calculated the proportional increase in the thinning

areas in Furano and Shimokawa by dividing the area where thinning had been conducted in stands that had not be previously thinned since 1990 by the total area that had been thinned. By comparing the increases in this thinning ratio between Furano and Shimokawa, we were able to calculate the difference in the relative increases in thinning areas associated with the different subsidy systems using ArcGIS 9.3 software (ESRI).

Simulating the impact of silvicultural subsidy systems on the jointly implemented thinning area

To simulate the spatial distribution of thinning areas, we constructed an algorithm to calculate the jointly implemented thinning areas, and their locations, as a function of the silvicultural subsidy system and geographic information about the two study regions (Fig. 2).

Based on information obtained from the forestry associations in the study regions, sub-compartments to predict the jointly implemented thinning area were selected by considering the following five factors: sub-compartment area, the address of the forest owner, the distance of the forest from the nearest forest road, slope of the site, and historical records of silvicultural practices. These factors were chosen for determining sub-compartments where jointly implemented thinning was likely to occur because conditions promote thinning efficiency when: the sub-compartment area is greater than 3 ha, there is a forest road within 10 m and the slope of the ground is less than 10 degrees. The planning and implementation of joint thinning operations is also facilitated when owners are living in their forest, and the silvicultural records showing the sub-compartments where silvicultural practices have been implemented indicate that these forest owners manage their forests more actively than other private owners. The number of the above criteria that promote jointly implemented thinning met in each sub-compartment was counted and entered as the parameter i_{id} in the algorithm based on the GIS information and forest inventory data. Based on information from the forestry associations we then identified sub-compartments in which thinning may occur in the simulations as those that that met two or more ($i_{id} > 2$) of the five conditions, and defined them as the prior set.

The adjacent sub-compartments in the prior set were then aggregated as jointly implemented thinning areas, excluding those for which: (1) there was a historical record of thinning during the last five years, (2) the stand was less than 10 years old, (3) there was no historical record of thinning during the last 30 years, (4) it was more than 1500 m from a forest road, or (5) the stand slope was more than 20 degrees. When considering the existing subsidy system, if the historical records indicated that thinning had occurred during the last five years it was not possible to apply for a subsidy for the stand. If the sub-compartment was greater than 1500 m from a forest road or the stand slope was greater than 20 degrees it was considered unsuitable for implementing thinning. If there was no historical record of thinning during the last 30 years, we considered the forest to be 'unmanaged', and a stand age of less than 10 years implies that the sub-compartment is not suitable for thinning based on the existing stand density control plan.

In Shimokawa, sub-compartments that were more than 35 years old were not aggregated because of the age limit in the subsidy system. In contrast, this limit was not imposed in Furano because the subsidy system can be used for stands of all ages at this site. Using our algorithm, we estimated the jointly implemented thinning area in Furano and Shimokawa. The jointly implemented thinning areas estimated by this algorithm were then compared with the actual areas calculated from historical records of silvicultural practices and GIS information.

Finally, after checking the accuracy of the estimated joint implemented thinning areas, the effect of the different subsidy systems on the potential extent and distribution of the thinning areas was simulated. By conducting simulations for the total areas in Furano and Shimokawa, areas that could be suitable for jointly implemented thinning under the existing and other subsidy systems were then identified.

Results and discussion

Calculation of the jointly implemented thinning area

Figure 3 shows the distribution of planted forests in size (area) classes, based on data regarding the sub-compartment areas in Furano and Shimokawa; a Chi-square test showed that there was no significant difference between these distributions (p value, 0.60; χ^2 value, 2.75). Table 1 shows the characteristics of the sites, including

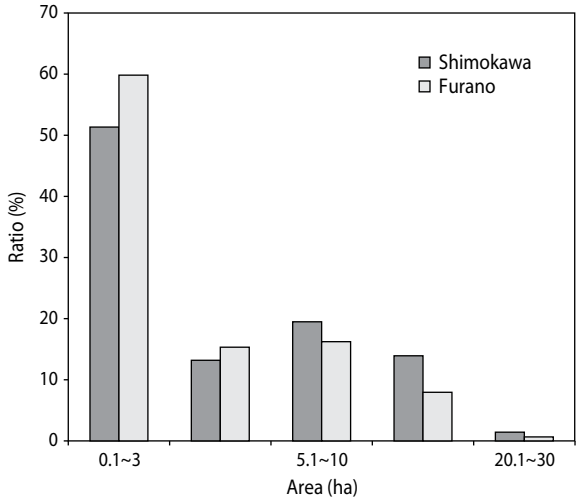

Fig. 3. Distributions of planted forests in area classes, based on the sub-compartment area in Furano and Shimokawa

Tab. 1. Means, standard deviations, maximum and minimum values for the utilized parameters at the two study sites

Study sites	Items	Units	Mean	Std Dev	Min	Max
Furano	Distance from forest road	m	842	540	0	3148
	Stand slope	degree	6	4	0	21
	No. of adjacent sub-compartments per sub-compartment	number	3	0	1	17
	Sub-compartment area	ha	1,00	1,81	0,01	42,17
	Stand age	year	41	13	2	101
Shimokawa	Distance from forest road	m	541	143	0	1486
	Stand slope	degree	4	2	0	13
	No. of adjacent sub-compartments per sub-compartment	number	3	0	1	14
	Sub-compartment area	ha	1,22	0,88	0,03	35,36
	Stand age	year	34	13	2	101

the distance from the nearest forest road, stand slope, and stand age. The distance from the nearest forest road and the stand slope observed in Shimokawa were higher than in Furano, but the observed number of adjacent sub-compartments and sub-compartment areas in Furano and Shimokawa were very similar. This information suggests that the differences in jointly implemented thinning area at the two sites are mainly due to differences in the subsidy system.

Both the overall extent and spatial distributions of jointly implemented thinning sub-compartment areas differed between Furano and Shimokawa (Fig. 4); the overall extent of these areas in the two regions was 286 ha and 85 ha, respectively, and the average size of the areas was 11 ha and 3 ha, respectively.

The total number of thinned sub-compartments in Furano and Shimokawa was 859 (average 1.1 ha) and 249 (average 1.8 ha), respectively. Although the distance from a forest road in Furano was generally greater than in Shimokawa, stands in the two regions were similar in terms of the other measured variables (Tab. 1). Nevertheless, the jointly implemented thinning area was approximately four times higher in Furano that in Shimokawa. This suggests that the relaxation of the subsidy rules in Shimokawa resulted in an increase in the area in which thinning was jointly implemented.

The ratio (percent) of unthinned to thinned stand area in Furano and Shimokawa was 42% and 33% in 2004, respectively. In contrast, the ratio of thinned area to unthinned area at locations where thinning had not been implemented since 1990, was 54% and 8% in Furano and Shimokawa, respectively. These results suggest that the size of the unthinned area has dramatically declined in Furano, compared with Shimokawa.

The reason for this is that unthinned stands could only be included in jointly implemented thinning areas in Furano by expanding the subsidy rules to include older forests. In addition, the expansion of the jointly implemented thinning area increased the efficiency of constructing forest roads. Thinning implementation and the construction of forest roads to access the targeted thinning area should be conducted simultaneously in these study sites. The increased accessibility that would be created by constructing forest roads is an additional reason for expanding the thinning area in unthinned stands. In other words, these results suggest that the jointly implemented thinning improved the freedom and efficiency of forest road construction, enabling access to unthinned stands. Thus, the thinning area could

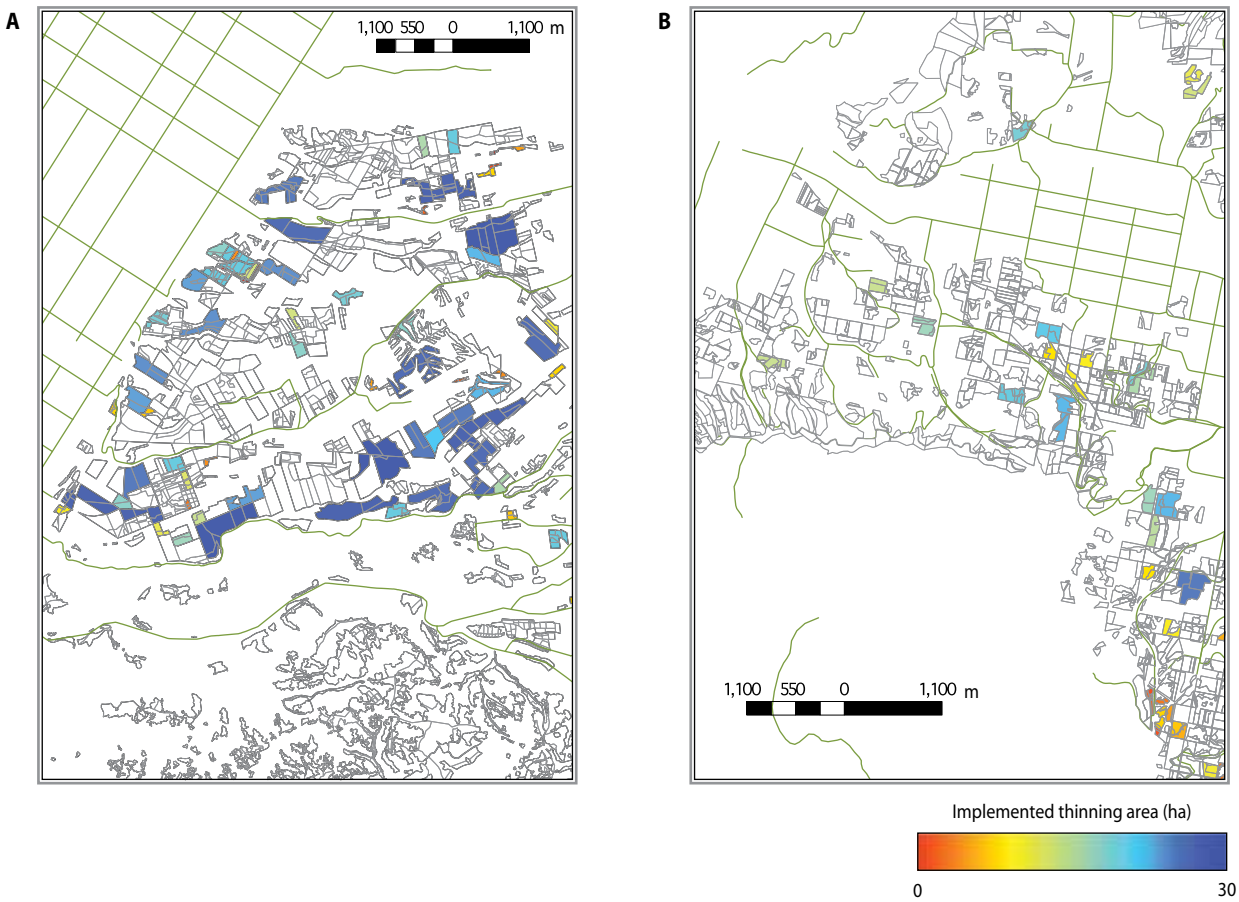

Fig. 4. Differences in the implemented thinning areas in Furano (A) and Shimokawa (B)

be expanded in Furano. In Shimokawa, the jointly implemented thinning area was lower than that in Furano. Therefore, we concluded that the forest road construction efficiency has not improved in Shimokawa. This is one of the indirect reasons that the larger thinning area (in locations where thinning had not been implemented before 1990) was observed in Furano.

Previous studies (Hiroshima and Nakajima 2006; Nakajima et al. 2007) have suggested that expanding the jointly implemented thinning area in Furano would require an increase in the maximum age of the stands that are eligible for subsidy. Nakajima et al. (2007) also suggested that this strategy would increase thinning area. Based on the results from Furano and Shimokawa, which have different subsidy systems and implement different thinning regimes, we suggest that the area of thinned forest could be increased by expanding the range of subsidies available to support thinning.

Simulating the impact of silvicultural subsidy systems on potential thinning areas

Our results showed that the algorithm we developed could estimate the likelihood that joint implemented thinning area would occur under different subsidy systems (Fig. 5). The coefficients of determination (R^2) for these areas in Furano and Shimokawa were 0.88 and 0.89, respectively, with root mean square errors (RMSE) of 5.0 and 1.5, respectively.

The slopes of the regression lines of observed versus thinning areas for Furano and Shimokawa were 0.77 and 0.84, respectively (solid lines, Fig. 5), indicating that the algorithm slightly overestimated jointly implemented thinning areas. Based on information from the survey regarding decisions of whether or not to implement joint practices, we found that some forest owners preferred not to collaborate with other forest owners under conditions proposed by the local forestry associations. For this rea-

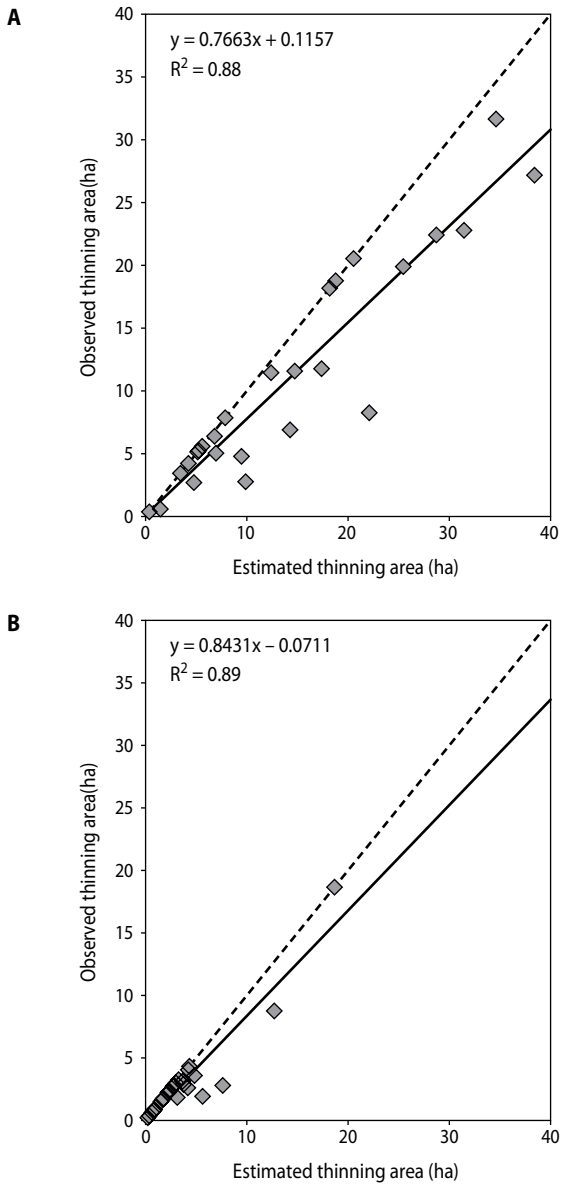

Fig. 5. Relationships between observed and estimated jointly implemented thinning areas in (A) Furano and (B) Shimokawa. The solid lines and broken lines show the regression lines and identity lines ($y = x$), respectively

son some forest owners probably decided to implement thinning independently, while others may have cooperated at a personal level to jointly implement thinning. Although such relationships between individual forest owners may hinder the establishment of a regional-level jointly implemented thinning program, it is difficult to formulate and include relationships like this in our algorithm. Therefore, the estimated value of the jointly implemented thinning area derived from the algorithm was an overestimation, and there were no underestimations in the estimated values. The major reason for the differences between the two study regions appears to be the difference in constraints for thinning subsidies applied by the local governments, which were included in our algorithm; hence, the coefficient of determination and RMSE were higher for Shimokawa than for Furano. The standard deviations of the error calculated by subtracting the observed jointly implemented thinning area from the estimated jointly implemented thinning area in Furano and Shimokawa were 4.0 and 1.3, respectively. These results suggest that the accuracy of the estimated value was lower for Furano than for Shimokawa. As mentioned above, there is less availability of subsidies in Furano compared with Shimokawa. This means that thinning can be jointly implemented with fewer restrictions in Shimokawa, although the extent of thinning depends on the specific forest owner. Therefore, the difference in the subsidy system between Furano and Shimokawa is one of the reasons that the accuracy of estimated values was lower for Furano than for Shimokawa.

The two-sided 95% confidence intervals of the observed mean jointly implemented thinning areas at Furano and Shimokawa ranged from 7.7 to 14.3 and 1.8 to 4.3, respectively. The estimated average jointly implemented thinning areas for Furano and Shimokawa were 14.2 and 3.7 ha, respectively; within the confidence intervals of the observed average values. These results indicate that our algorithm can validly estimate the average jointly implemented thinning area under different subsidy systems.

The spatial distributions of potential implemented thinning area under the two different subsidy systems in Furano and Shimokawa were visually displayed, as shown in Fig. 6. Figure 7A shows the distribution area class ratio between the potential thinning area and the total sub-compartment area in Furano and Shimokawa. A Chi-square test showed that there was a significant difference between the distributions observed for Furano and Shimokawa (p value < 0.01, χ^2 value: 26.92). The total potential joint implemented thinning area in Furano and Shimokawa was 3,292 ha and 771 ha, respectively. The average joint implemented thinning area in Furano and Shimokawa was 9.4 ha and 3.2 ha, respectively.

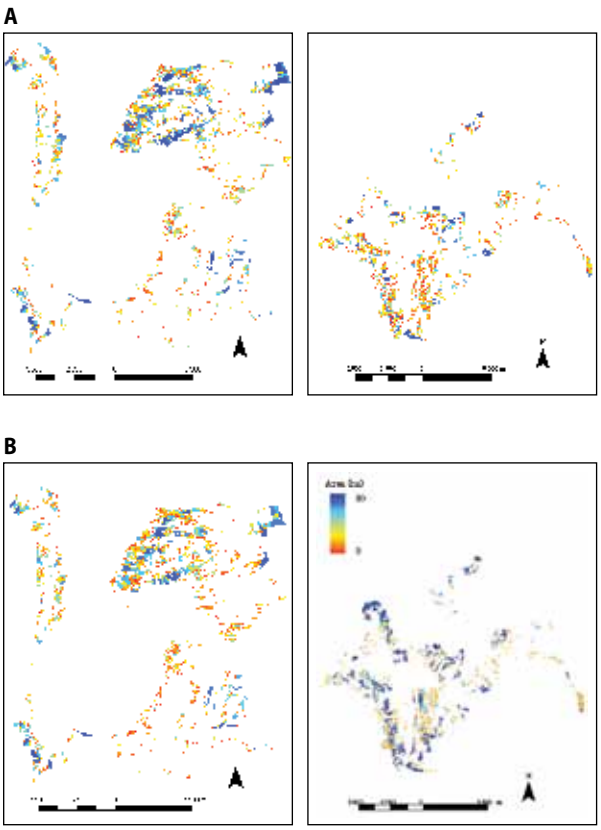

Fig. 6. Comparison of the implemented spatial thinning area distributions simulated by our algorithm for Furano and Shimokawa under (A) the existing subsidy systems and (B) the subsidy systems reversed at the two sites

Figure 7B shows the distributions of potential thinning areas in size classes, based on the sub-compartment areas in Furano and Shimokawa, if the two subsidy systems were reversed. A Chi-square test showed that there was a significant difference between the distributions observed in Furano and Shimokawa (p value < 0.01, χ^2 value: 30.61). The total potential jointly implemented thinning areas in Furano and Shimokawa were 311 ha and 2,178 ha, respectively, while the average areas were 3.5 ha and 5.2 ha, respectively. However, comparing figures 6A, b and 7A, B it can be seen that the pattern of a large thinning area in Furano and a small thinning area in Shimokawa would be reversed if the subsidy systems were reversed. These findings show that the effects of different silvicultural subsidy systems can be simulated by applying the developed model, confirming and extending the finding that it can estimate with confidence the likelihood that joint implemented thinning will occur under different subsidy systems (Fig. 5). Therefore, these simulations can help to predict the cost-effectiveness of subsidies for expanding the thinned stand area, which should help to improve the status of private forests.

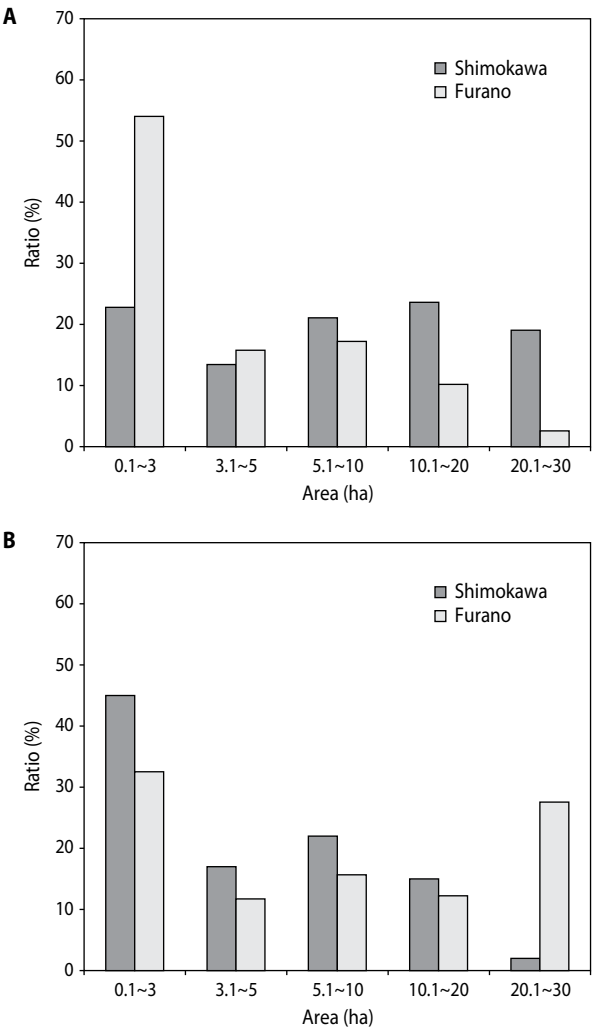

Fig. 7. Simulated distributions of the potential thinning areas in size classes in Furano and Shimokawa under (a) the existing subsidy system and (b) the reversed subsidy systems at the two sites

Using our algorithm, which considered spatial information, and data on the subsidy type and stand conditions, we assessed the effects of implementing thinning. Previous studies have analyzed useful vari-

ables and estimated parameters for several econometric models including the probit model (Dennis 1990; Pattanayak et al. 2003) and the logistic regression model (Royer 1987; Zhang and Pearse 1997), which can be used to predict effects of forestry policies and subsidy systems. Other previous studies (Bolkesjø and Baardsen 2002; Kurttila et al. 2006; Lewis and Plantinga 2007) have created models to estimate the effects of different amounts of subsidy. When these scenario-based approaches are used and if the subsidy system is changed (for example the target stand age is changed) then the parameters and variables for these models may need to be re-estimated. In contrast, our algorithm enables us to simulate the spatial distribution of thinning area under different subsidy systems by using the conditions and scenarios in which subsidies are applicable. For example, we could simulate the changes in jointly implemented thinning areas under two different subsidy systems in Furano and Shimokawa (Figs. 6, 7).

Gottschalk et al. (2007) conducted simulations and produced visualizations of the effects of policy decisions on forestry management by linking GIS and scenario-based approaches. These previous studies allowed decision-makers to link policy, land-use, and biodiversity management. In addition, Hiroshima and Nakajima (2006) developed a statistical model for simulating total silvicultural practice areas in Japan under different subsidy levels. By linking simulations of the total thinning area based on the previous study of Nakajima et al. (2007) and the spatial distribution of the jointly implemented thinning area, it would be possible to estimate the effect of different subsidies on thinning regimes. In other words, by considering the geographical locations and conditions of stands, it should be possible to identify the most effective subsidy system to promote desired forest management practices.

Many previous studies (Barrett et al. 1998; McDill et al. 2002; Batten et al. 2005) have estimated the economic cost of restricting jointly implemented harvesting. An advantage of our algorithm, compared to the models developed in the cited studies, is that it can be used to estimate the overall benefits of jointly implemented thinning by considering scaling effects, calculated using GIS information. Further, since Japanese forestry profits have been decreasing, there is a need to improve forestry income and expand the managed forest area (which are affected by the subsidy system) to obtain economies of scale. It should therefore be possible to determine an optimal subsidy system for expanding the thinning area to desired levels using our algorithm, and thus improve profitability.

Since the spatial distribution of the thinning area is related to the construction of new forest roads for harvesting, it is also possible to simulate forestry road construction (Gumus et al. 2008) and develop timber harvesting plans (Prestemon and Wear 2000) based on the thinning area and subsidy system. The applicability of our simulation was based on Japanese forestry being strongly supported by government subsidies. Japanese forestry is significantly affected by the subsidy system because profits have decreased due to reductions in timber prices (Forestry Agency 2007). Based on the current social situation in Japan, almost all of the thinning area could be estimated by the type and the amount of subsidy (Nakajima et al. 2007). Therefore, if we can include the subsidy conditions for thinning in the algorithm, we can predict the spatial thinning area distribution. Further, since the main Japanese forest subsidy regime is applied uniformly throughout Japan, this approach could be applied to other regions in Japan.

The Hokkaido region has relatively flat ground compared to other areas in Japan, therefore it would be important to consider any restrictions resulting from the nature of the plot/resource (such as the presence of a mountain edge or valley) when considering thinning in other regions. Moreover, if Japanese socio-economic conditions, such as forestry policy and profits based on timber prices, change dramatically, our algorithm (which is based on the existing policy and subsidy system) will be unable to predict spatial thinning area distributions in private forests. However, the economic conditions of Japanese forestry, the total silvicultural area and the subsidy system have not changed dramatically in the past 10 years (Hiroshima and Nakajima 2007). Thus, assuming that the socio-economic conditions of Japanese forestry conditions continue to be similar, our algorithm could be used to simulate the spatial thinning area distribution under different subsidy systems and different levels of financial support.

Conclusions

In this study, spatial thinning area was analyzed for different subsidy systems and modeled using a developed algorithm that considered restrictions imposed by the subsidy system and stand conditions. The results suggest that in a region where the subsidy system was relaxed, the jointly implemented thinning area increased and (hence) the unthinned area dramatically declined. Although our predictions for the jointly implemented thinning area were overestimates, the algorithm we developed successfully simulated the relationship between the jointly implemented thinning area and subsidy system. Based on this simulation, we were able to predict the stand condition and the effect of implementing thinning and visualize the effects of different subsidy systems by linking the results to a GIS.

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